HOT AND COOL: BRIDGING GAPS IN MASSIVE-STAR EVOLUTION
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Three Concurrent Phases of Massive-Star Evolution in a Pulsar-Wind Nebula

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Abstract. The nebular material associated the the SNR G54.1+0.3 (hereafter G54) contains the the first reported instance of triggered star formation in the immediate vicinity of a Pulsar and its Wind Nebula (PWN). With 2MASS and *Spitzer* colors and followup near-IR spectroscopy, we have discovered the presence of a hot, massive and most likely evolved Be-type star among the cluster of stars hosted by the pulsar. This star has probably triggered cloud collapse and formation of at least 11 YSOs, which ring the nebula. In this unique cluster are now identified three concurrent stages of stellar evolution, from massive star birth, post-Main-Sequence transition, and stellar death.

A host of massive Young Stellar Objects (YSOs) has been recently discovered by Koo et al. (2008) with mid-infrared AKARI and *Spitzer Space Telescope* imaging of the IR ring associated with the young core-collapse Type II SNR G54.1+0.3, and is the first reported instance of triggered star formation in the immediate vicinity of a PWN. The SN event is estimated to have occurred ∼2900 years ago, while the initiation of cloud collapse may have occurred up to 2 Myr ago, based on kinematical considerations for dispersing $\sim 100\,M_\odot$ of the 11 massive ($>10\,M_\odot$) YSOs, at $0.2\,\mathrm{km\,s^{-1}}$ to their projected distances from the pulsar of ∼2 pc, at an overall distance of 8 kpc. Instead of the SNR itself as a triggering mechanism, the wind from a $15\,M_\odot$ progenitor near the end of its post-Main-Sequence lifetime is speculated to be the triggering star. The progenitor must have been near the end of its lifetime to fit the approximate age of the YSOs, and is bound in initial mass by these dynamical ages, plus the notion that a more massive star will have a more destructive impact on the natal cloud which presently has a regular, ring appearance. It is a tight fit of the progenitor's parameters to explain the presence of the massive YSOs.

We have serendipitously discovered a significant source of dynamical influence and energy input into the IR ring associated with G54, namely an evolved hot star whose near-infrared spectral properties indicate an early-type B supergiant and potential Luminous Blue Variable (LBV) star. The star was discovered as part of our program to exploit 2MASS JHKs and *Spitzer* IRAC colors of Wolf-Rayet stars to reveal new members of this rare but energetically and chemically influential class of evolved (pre-SN Type Ib/c) massive stars, hiding behind large amounts of optical extinction (Hadfield et al. 2007; Maurehan, van Dyk, & Morris 2009).

By comparison to similar spectra of early-type B supergiants (some also LBVs), especially to the extreme P Cyg-type star HDE 316285, we expect the stellar and wind parameters of the G54 LBV to be somewhere around $T_\star \simeq 15\,\mathrm{kK}$, $\log(L/L_\star) \simeq 5.4$, $\dot{M} \simeq 2.5 \times 10^{-4}\,M_\odot\,\mathrm{yr}^{-1}$, $v_\infty = 450\,\mathrm{km\,s}^{-1}$. Detailed modeling with CMFGEN is in progress so that we can quantitatively ascertain the radiative and mechanical role of this star in relation to the pulsar and YSOs, but clearly it offers a more attractive alternative for initiating a cloud-collapse star within the last 2 Myr.

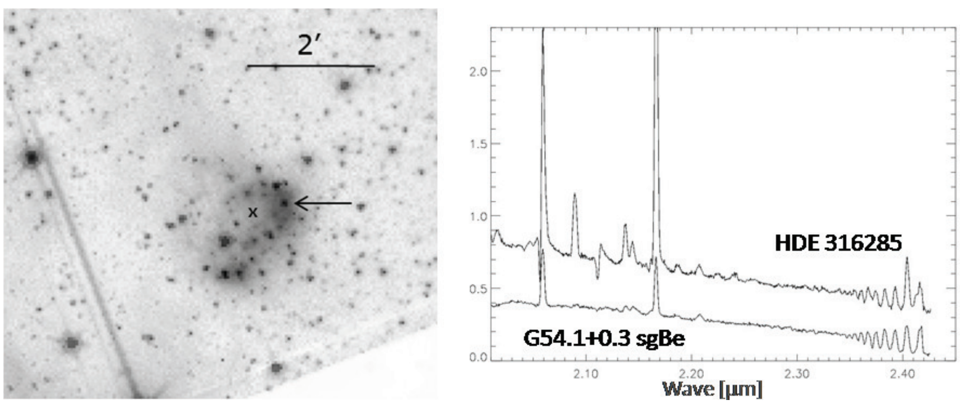

Figure 1. *Left*: *Spitzer* IRAC 5.8, 8.0 and MIPS 24 μm composite image (reverse grayscaled), showing the location of the 136 millisec radio/X-ray pulsar ('x') and the newly identified emission line B-type star (arrow). *Right*: Comparison of the IRTF K band spectra of the B star in G54, to the extreme P Cyg star HDE 316285.

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